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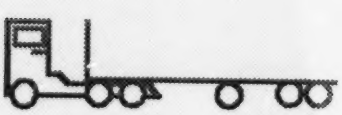
Demonstration of Tractor-Trailer Performance: 7-Axle 48 ft Semi



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Demonstration of Tractor-Trailer Performance: 7-Axle 48 ft Semi

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Prepared for:
CCMTA/RTAC Vehicle Weights and Dimensions Study

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Abstract:
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The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with the empty vehicle on a low-friction surface and the loaded vehicle on a high-friction surface.

This report presents detailed results of the tests and demonstrations.

Key Words: truck testing, offtracking, truck turning, air brake system, braking, truck dynamic tests, rearward amplification, rollover, lane change, tilt test

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ABSTRACT

A 7-axle 48 ft (14.63 m) semitrailer combination was tested by the Ontario Ministry of Transportation and Communications (MTC) as part of the CCMTA/RTAC Vehicle Weight and Dimensions Study. The vehicle was designated an additional vehicle by the study.

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TABLE OF CONTENTS

	PAGE
1/ INTRODUCTION	1
2/ TEST VEHICLE DESCRIPTION	2
3/ TEST PROGRAM	4
3.1/ Test Procedures	4
3.2/ Instrumentation	5
3.3/ Data Capture and Data Processing	5
4/ RESULTS	7
4.1/ Offtracking	7
4.2/ Right-Hand Turn	7
4.3/ Channelized Right Turn	8
4.4/ Air Brake System	8
4.5/ Straight-Line Braking	9
4.6/ Evasive Manoeuvre	10
4.7/ Sinusoidal Steer	10
4.8/ Lane Change	11
4.9/ Normal Straight-Line Driving	11
4.10/ Steady Circular Turn	12
5/ DISCUSSION	14
6/ CONCLUSIONS	15
7/ REFERENCES	16

LIST OF FIGURES

PAGE

1/ 7-Axle 48 ft Semi, View of Vehicle. 18
2/ 7-Axle 48 ft Semi, Vehicle Dimensions 18
3/ 7-Axle 48 ft Semi, Offtracking. 19
4/ 7-Axle 48 ft Semi, Clockwise Final Offtracking 19
5/ 7-Axle 48 ft Semi, Right-Hand Turn Swept Path 20
6/ 7-Axle 48 ft Semi, Right-Hand Turn. 21
7/ 7-Axle 48 ft Semi, Channelized Right Turn 21
8/ 7-Axle 48 ft Semi, Channelized Right-Turn Clearance from Inner Curb 22
9/ 7-Axle 48 ft Semi, Air Brake System Schematic 23
10/ 7-Axle 48 ft Semi, Air Brake Application and Release 24
11/ 7-Axle 48 ft Semi, Vehicle Response to Straight-Line Braking. 25
12/ 7-Axle 48 ft Semi, Straight-Line Braking Responses vs Treadle Valve Pressure 26
13/ 7-Axle 48 ft Semi, Evasive Manoeuvre, Peak-to-Peak Responses vs Speed 27
14/ 7-Axle 48 ft Semi, Vehicle Response in Evasive Manoeuvre. 28
15/ 7-Axle 48 ft Semi, Rearward Amplification of Lateral Acceleration 29
16/ 7-Axle 48 ft Semi, Vehicle Response to Sinusoidal Steer at 94 km/h 30
17/ 7-Axle 48 ft Semi, Lane Change, Vehicle Responses vs Speed. 31
18/ 7-Axle 48 ft Semi, Lane Change, Vehicle, Responses at 94 km/h. 32
19/ 7-Axle 48 ft Semi, Steady Circular Turn, Vehicle Responses vs Tractor Lateral Acceleration 33
20/ 7-Axle 48 ft Semi, Steady Circular Turn, Vehicle Responses at 53 km/h. 34
21/ 7-Axle 48 ft Semi Wear Pattern on Right Rear Outer Tire After Steady Circular Turn Test. 35
22/ 7-Axle 48 ft Semi on Tilt Table 35

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1/ INTRODUCTION

The effects of changes in truck weight and dimension parameters on combination vehicle stability and handling and on pavement response to axle group loading are being examined in the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle portion of the study involved both computer simulation of vehicle dynamic manoeuvres and testing of vehicles and components. Combination vehicles were classified into six families, based on the number of trailers and methods of hitching. A representative of each family was designated as the baseline vehicle configuration for that family. Additional vehicle configurations of interest were also defined. All baseline and additional vehicle configurations were tested to assemble a body of technical and visual data that described the stability and control characteristics of the vehicles with respect to certain performance measures.

The Ontario Ministry of Transportation and Communications (MTC) was asked to test the six baseline vehicles and three additional tractor-trailer combinations, as part of its contribution to the study. This report presents the results of a test of a 7-axle 48 ft (14.63 m) semitrailer combination, which is one of the additional vehicles. It refers frequently to a report describing procedures and equipment common to tests of all nine vehicles undertaken by MTC [1]. Similar reports present details of the tests of the other eight vehicles [2-9], and a summary report presents the results of tests of all six baseline vehicles [10]. A computer simulation of vehicle responses to actual test inputs using estimated vehicle data has also been conducted [11].

2/ TEST VEHICLE DESCRIPTION

The test vehicle consisted of the MTC Freightliner [1] and single 48 ft (14.63 m) four-axle flatbed-type semitrailer. The combination is typical of equipment used in Central Canada, where additional gross weight can be carried on a widespread tandem axle and belly axles. The same combination was also tested concurrently as a 5- and 6-axle vehicle [8,9].

The equipment for these tests was provided by the Roads and Transportation Association of Canada (RTAC). No modifications were made to the trailer except for purposes of attachment of test equipment, which had no effect on the operation of the vehicle, though unit weights and polar moments of inertia were affected.

The trailer was manufactured by Fruehauf in July 1984 and was a 48 ft (14.63 m) flatbed semitrailer with two fixed and two airlift axles. It was model PBX4W 48102 and bore the serial number 2H8P04843ER033601.

The trailer had a nominal length of 14.63 m (48 ft) and a nominal width of 2.59 m (102 in). The trailer suspension comprised a Reyco four-spring leaf system with long equalizer arms on the fixed axles and a Neway air suspension system for the two airlift axles. The axle spacings were 2.74, 2.74, and 2.77 m (108, 108, and 109 in). The spring centre width was 0.96 m (38 in) for the fixed axles and 0.76 m (30 in) for the airlift axles. The airlift axles had shock absorbers in parallel with the air springs, with a spacing of 0.30 m (12 in). The track width was 2.44 m (96 in). The vehicle overall length was 18.69 m (61.32 ft). The trailer was rated at 9620 kg/axle (21 164 lb/ axle).

The trailer was fitted with new Michelin XZA radial tires, in load range H and size 11R22.5. These tires were run a nominal distance of 160 km (100 mi) before any testing and were then, subsequently, used for all tests. Tire pressure was set cold at 689 kPa (100 psi), which is the manufacturer's recommended value for full load. This was used for all tests and represents the common operating practice of not reducing tire pressure when running empty.

The test vehicle is shown in Figure 1, in test condition with outriggers installed. The dimensions of the test vehicle are presented in Figure 2. Empty weight of the combination in test condition was 22 595 kg (49 710 lb). Concrete blocks were used to obtain a loaded weight of 49 898 kg (109 730 lb). Airlift axle pressure was 110 kPa (16 psi) in

each axle for the empty vehicle and 345 kPa (50 psi) loaded. Axle loads in these conditions are given in Table 1.

Table 1/ Axle Loads

Axle No.	Empty		Loaded	
	(kg)	(lb)	(kg)	(lb)
1	4 918	10 820	5 255	11 560
2	3 885	8 547	7 923	17 430
3	3 885	8 547	7 232	15 910
4	2 477	5 449	7 464	16 420
5	2 477	5 449	8 177	17 990
6	2 477	5 449	6 577	14 470
7	2 477	5 449	7 250	15 950
Total	22 595	49 710	49 878	109 730

The empty weight exceeds that which would normally be seen on the highway, because the tractor is considerably heavier than late-model equipment and because of the weight of test equipment installed, particularly the outriggers. A target axle load of 8000 kg (17 600 lb) was set for all axles except for the steer axle. This was closely attained, with the exception of the tractor drive axles. The legal gross weight for the vehicle tested is about 56 000 kg (123 200 lb) in Ontario.

The height of the centre of gravity of the empty trailer sprung mass was estimated as 0.26 m (10 in) below the top of the floor. The centre of gravity height was estimated as 0.27 m (10.5 in) above the top of the floor in the loaded condition.

3/ TEST PROGRAM

3.1/ Test Procedures

The test vehicle was prepared for testing in the following way:

1/ A mechanical inspection was carried out, and any necessary repairs or maintenance was done.
2/ Outrigger and safety cable attachments and load block retention sills were installed on the trailer.
3/ Outriggers were installed on the trailer.
4/ The boxes containing instrument packages, power supplies and signal conditioning, other instruments, and cabling were installed.
5/ New tires were installed, and pressures were set.
6/ Other fittings necessary for testing were installed.
7/ Concrete blocks were located on the trailer bed to achieve specified axle loads.
8/ Notes were made from detailed physical inspection, including an inventory of components and measurement of dimensions.
9/ The MTC tractor was coupled to the trailer.
10/ The combination vehicle was weighed, empty and loaded.
11/ A functional test of the on-board electronics was conducted.
12/ Test runs were made to shake down the vehicle instrumentation and familiarize the test driver with the vehicle's handling characteristics.
13/ Tires were run a nominal distance of 160 km (100 mi).
14/ Articulation angle between the tractor and trailer was calibrated.
15/ Photographs and video film were taken to record details of the vehicle and test equipment.

The following tests were performed:

- Offtracking
- Right-hand turn
- Channelized right turn
- Air brake system
- Straight-line braking, empty vehicle, low-friction surface
- Evasive manoeuvre, empty vehicle, low-friction surface
- Sinusoidal steer, loaded vehicle, high-friction surface
- Lane change, loaded vehicle, high-friction surface
- Normal straight-line driving
- Steady circular turn, loaded vehicle, high-friction surface

All tests followed standard procedures [1], except as noted.

3.2/ Instrumentation

The instrumentation shown in Table 2 was installed. Brake pressure transducers were only installed in the trailer for the air brake system test, but all other instrumentation was installed for all tests. Data were always captured from all instrumentation, but only those pertinent to a particular test were analysed.

Tractor instruments were selected from the instrumentation that is permanently installed on the tractor. Instruments for the trailer were mounted in a box placed on the trailer deck, which also contained power supplies and signal conditioning. Trailer lateral acceleration and roll angle were measured at a point midway between the kingpin and axle.

Full details of the instrumentation, signal conditioning, and data capture system are presented elsewhere [1].

3.3/ Data Capture and Data Processing

Data were digitized on board the vehicle and transmitted by telemetry as a pulse-code modulated (PCM) data stream to a ground station, where they were recorded on magnetic tape and captured in real time by an HP-1000 computer system. Test data for a run were processed immediately after the run, and results from a series of runs were subsequently analysed using the computer system [1].

Many test runs of all types were conducted for this vehicle. Not all these runs were used in the preparation of this report. In a number of instances, a run failed to meet a test condition, or runs were made to evaluate the ability of the vehicle to make a particular manoeuvre.

Table 2/ Instrumentation Installed

No	Measurement	Instrument	Full Scale
1	Tractor steer angle	Spectrol 139 potentiometer	25.02°
2	Tractor roll angle	Humphrey CF18-0907-1 gyro package	8.85°
3	Tractor lateral acceleration	Kistler 303B accelerometer	0.957 g
4	Tractor yaw rate	Humphrey RT03-0502-1 angular rate transducer	38.7°/s
5	Tractor longitudinal acceleration	Kistler 303B accelerometer	0.974 g
6	Tractor speed, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	104.8 km/h
7	Tractor distance, axle 1 right	Airpax 087-304-0044 zero velocity magnetic pickup	56.3 m/ramp
8	Tractor fifth wheel load, left-hand side	MTC load cell	9890 lb
9	Tractor fifth wheel load right-hand side	MTC load cell	10290 lb
10	Tractor treadle valve pressure	Celesco PLC-200G	100 psi
11	Tractor brake pressure, axle 2 Left	Celesco PLC-200G	99.80 psi
12	Tractor lateral acceleration at fifth wheel	Columbia SA-107 accelerometer	0.996 g
13	Tractor yaw angle	Humphrey CF18-0907-1 gyro package	17.73°
14	Trailer 1 articulation angle	Celesco pull cord DV-301-150	19.792°
15	Trailer 1 lateral acceleration	Columbia SA-107 accelerometer	0.995 g
16	Trailer 1 roll angle	Humphrey VM02-0128-1 vertical gyro	8.90°
17	Trailer 1 outrigger touchdown	Strain gauge bridge	1.0 V
18	Dolly 1 hitch angle	Spectrol 139 potentiometer	25.0°
19	Dolly 1 lateral acceleration	Columbia SA-107 accelerometer	0.996 g
20	Brake pressure, axle 4 right	Celesco PLC-200G	104.96 psi
21	Brake pressure, axle 5 right	Celesco PLC-200G	101.06 psi
22	Brake pressure, axle 6 right	Celesco PLC-200G	102.07 psi
23	Brake pressure, axle 7 right	Celesco PLC-200G	101.93 psi

4/ RESULTS

4.1/ Offtracking

Steady-state offtracking is considered an indicator of vehicle turning ability. Offtracking of the vehicle was evaluated by making a complete turn around a circle of radius 29.87 m (98 ft). The vehicle outer wheel tracked the inside of the circle. Turns were made in both directions, as shown in Figure 3. At the end of a turn, the vehicle was parked and the radius to each axle was measured, according to the standard test procedure [1].

The results are shown on Table 3. The measured data were averaged for the left and right turn and then compared to data generated by a simple offtracking formula [12]. The difference between actual and computed values shown in the last column of Table 3 is so small that steady-state offtracking can clearly be estimated very accurately by this simple formula.

The final offtracking for the counter-clockwise turn is shown in Figure 4.

Table 3/ Offtracking

Axle No.	Track Width	Radius to Inner Wheel		Difference (m)	Average (m)	Calculated (m)	Difference %
		Right Turn (m)	Left Turn (m)				
1	2.31	27.59	27.44	0.15	27.51	27.56	+0.20
2	2.37	27.40	27.35	0.05	27.38	27.21	+0.62
3	2.37	27.44	27.42	0.02	27.43	27.21	+0.80
4	2.37	26.13	26.13	0.00	26.13	26.12	+0.03
5	2.37	25.63	25.63	0.00	25.63	25.83	+0.77
6	2.37	25.35	25.39	0.04	25.37	25.83	+1.70
7	2.37	25.38	25.42	0.04	25.40	26.12	+2.75

4.2/ Right-Hand Turn

A 90° right-hand turn is a very demanding manoeuvre for a large truck. The vehicle's swept path in a 90° right-hand turn of 15 m (49.2 ft) radius was measured, according to the standard test procedure [1]. This radius is typical in an urban area or where there is limited truck traffic. The swept path is shown in Figure 5.

The vehicle is shown in Figure 6 during the turn, at a point close to its maximum excursion out of the exit lane. The maximum excursion out of lane was only 0.80 m (2.62 ft). It was out of the exit lane for a distance of 20.4 m (67 ft), as derived from Figure 5. This test was conducted at a creep speed and represents about the best possible turn. A rolling turn would probably result in a greater excursion out of the exit lane.

4.3/ Channelized Right Turn

The vehicle's swept path in a channelized right turn was measured according to the standard test procedure [1].

The vehicle is shown during the turn in Figure 7. The clearance of the innermost wheel of the rear trailer's rear axle from the inner curb is shown in Figure 8 as a function of distance through the curve. The minimum clearance was 1.47 m (4.8 ft) in the 5.5 m (18 ft) wide roadway.

The roadway geometry used for this test is typical of an urban area, where space is limited. The curb radius was 25 m (82 ft), and entry and exit tapers typical of four-lane roadways with a 60 km/h speed limit were used. Such geometrics would not appear to restrict access of this vehicle.

4.4/ Air Brake System

The air brake system of the combination was evaluated according to standard test procedure [1].

The trailer air brake system was inspected. A schematic of the system is shown in Figure 9. All slack adjusters required manual adjustment. Stroke was adjusted to the minimum, about 32 mm (1.25 in) on each axle. The tractor was supplied with shop air, regulated at 689 kPa (100 psi).

The SAE J982a style test was performed, and the results, presented in Table 4, are the average of several tests, each with a time resolution of 0.02 s. The application and release times of this test compare favourably with those obtained from tests on other similar combinations and are considered fast. A typical time history response of application and release is presented in Figure 10.

Table 4/ Air Brake Timing, SAE J982a Style Test

Location	Application Timing 0-60 psi (s)	Release Timing to 5 psi (s)	Final Pressure (psi)
Treadle	0.02	0.17	92.6
Axle 2	0.36	0.55	91.1
Axle 4	0.40	0.95	87.4
Axle 5	0.45	0.98	88.1
Axle 7	0.44	1.03	86.1

4.5/ Straight-Line Braking

It is difficult to conduct rigorous braking tests and achieve consistent results. A demonstration of modes of instability of the combination vehicle in straight-line braking was, therefore, conducted. A series of runs was made with the empty vehicle approaching the low-friction test area at 47 km/h and the driver braking using the treadle valve. Runs were made using various application pressures, to the point where groups of wheels locked. The driver was instructed not to attempt to counter any loss of control, except as necessary to avoid hazard. The standard test procedure was followed [1]. Note that the airlift axles were lowered for this test, even though they would be raised in normal operation on the highway when the vehicle was empty.

The vehicle combination was evaluated primarily in terms of the yaw response of vehicle units, which is the heading angle of the vehicle unit (in degrees), with zero parallel to the original direction of travel. Any significant yaw seen in this manoeuvre arose from lateral/directional instability of a vehicle unit.

The time history of a typical run that resulted in loss of control is shown in Figure 11. The initial average brake application of about 242 kPa (35 psi) caused all braked wheels to lock, and the tractor jackknifed hard to the right. The driver released the brakes, steered hard to the left to full lock, and managed to regain control of the vehicle at a low speed, although the vehicle was grossly distorted and far out of lane. The tractor heading shown in Figure 11 reached the limit of the signal conditioning.

A summary of peak vehicle responses is shown in Figure 12, as a function of average treadle pressure.

4.6/ Evasive Manoeuvre

The object of this test was to evaluate empty vehicle lateral/directional characteristics at the limits of stability on a low-friction surface. A series of runs was made where the driver made an evasive manoeuvre, which is considered representative of a high-speed accident avoidance situation on a two-lane, two-way highway. The test used gates of 22.5 m (73.8 ft) for the lane change to the left and the return to the original lane, separated by 20 m (65.6 ft) in the left lane. Note that the airlift axles were also lowered for this test.

The vehicle combination was evaluated primarily in terms of the lateral acceleration and yaw responses of the vehicle units. These are shown in Figure 13. Each response is the peak-to-peak amplitude experienced by the vehicle in the manoeuvre. The lateral acceleration amplitude of both tractor and trailer rose to 4 to 5 m/s^2 at 57.5 km/h. Vehicle heading angle tended to rise slightly as speed increased, indicating moderate slide within lane. Tractor steer corrections were such that a slight understeer effect was noticeable as speed increased. Indications of tractor slide became evident at the higher speeds. Tractor control appeared to be the limiting factor in this combination.

A typical run at 58 km/h is presented in Figure 14.

4.7/ Sinusoidal Steer

The objective of this test was to evaluate characteristics of rearward amplification of lateral acceleration for this combination. A series of runs was made where the driver made a sinusoidal steer input to the vehicle while travelling at a steady speed, in accordance with the standard test procedure [1]. This test was conducted at speeds of 63, 84, and 94 km/h, with steer input periods between about 2 and 5 s.

The vehicle combination was evaluated in terms of the lateral acceleration responses of the vehicle units. Rearward amplification of lateral acceleration is presented in Figure 15, as a function of tractor steer input period for the three test speeds. This is defined as the peak-to-peak trailer lateral acceleration response divided by the peak-to-peak tractor lateral acceleration, and is dimensionless.

It is evident from Figure 15 that rearward amplification increases little with speed. It is somewhat sensitive to steer period reaching the highest value of about 1.05 at around 3.5 s. The results show that, at highway speed, this is a very stable vehicle, because of low response to input.

Figure 16 shows the response of a typical run for a steer period of about 1.5 s at 94 km/h.

4.8/ Lane Change

The objective of this test was to evaluate vehicle stability characteristics in a dynamic manoeuvre. A series of runs was made where the driver made a lane-change manoeuvre, considered representative of a high-speed accident avoidance situation on a four-lane or divided highway. The runs were made in accordance with the standard test procedure [1].

The test used a gate of 30 m (98.4 ft) for the lane change. This was used to provide a vehicle speed of about 80 km/h, which is a typical speed limit and might permit some comparison of the results of this test with that described in the preceding sections.

The results from all runs are presented in Figure 17. The peak-to-peak lateral acceleration and roll angles and roll showed a moderate increase up to 95 km/h, and yaw stayed essentially constant. The trailer did not roll aggressively or slide in this manoeuvre. Lateral acceleration and roll gains are also shown in Figures 17. The lateral acceleration gain is consistent with the values from the sinusoidal steer test.

The yaw overshoot of the trailer is also shown in Figure 17, which illustrates rear trailer swing at all speeds.

Figure 18 shows a typical run time history at 95 km/h. Athough the vehicle appeared to stay in lane, the traces indicate the tractor and trailer manoeuvring or sliding within the confines of the lane.

4.9/ Normal Straight-Line Driving

The objective of this test was to evaluate lateral motion of the rear trailer of the combination, the phenomenon known as trailer sway. A series of runs was made with the loaded vehicle driven normally at 94 km/h in a straight line, according to the standard test procedure

[1].

As previously mentioned, the vehicle was very stable, and if any slight steer corrections made in the course of normal driving, and roughness of the test track surface, resulted in trailer sway, it was not readily perceptible to the occupants of a chase vehicle. Root mean square (RMS) lateral acceleration of the rear trailer was 1.04 g/° of RMS steer input.

4.10/ Steady Circular Turn

The objective of this test was to evaluate vehicle steady-state rollover characteristics to determine the high-speed offtracking of the vehicle and examine the side loads exerted on the tractor by the trailers. A series of runs was made with the vehicle circumscribing a circle with a 50 m (164 ft) radius at a steady speed, according to the standard test procedure [1].

The results of this test are summarized in Figure 19. The vehicle combination was evaluated primarily in terms of the roll response of the vehicle units. Average steady-state roll angle increased with speed. Average steady-state articulation angle is also shown in Figure 19. This decreased modestly with increase in lateral acceleration, and as a consequence, the offtracking decreased. The lateral force experienced by the tractor fifth wheel is shown in Figure 19, as a function of tractor lateral acceleration. This shows a gradient of 80.3 kN/g (18 000 lb/g).

At the limiting speed of 53 km/h, a lateral acceleration of 0.39 g, the driver was unable to hold the vehicle in circle because of the heavy steer effort required, as shown in Figure 20. The test was terminated at this point.

The slip angle at the rear axle of this vehicle, and the extremely high load on the right side, resulted in very severe wear of the outer shoulder of the outer tire on the right-hand side of the rear axle, as shown in Figure 21. There was lesser wear in a similar pattern on the inner tire at this position and the outer tire on the preceding axle. This wear pattern was initiated in the corresponding test of this trailer in the 5- and 6-axle configurations [8,9].

A tilt test was conducted on this vehicle as part of a separate test program [14]. The vehicle is shown on the tilt table in Figure 22. The

high-side wheels of the rear trailer lifted at a tilt angle of 29.1°, after all corrections were made, which corresponds to a lateral acceleration of 0.56 g. The lateral acceleration only reach 0.39 g in the steady circular turn, so it was not possible to compare the rollover threshold with the tilt test.

5/ DISCUSSION

Tests were conducted with the equipment as provided. No efforts were made to modify the equipment, except as required for testing, and these modifications did not affect vehicle operation.

Tests were conducted in various weather conditions. Tires wore progressively as the various tests were conducted, particularly those on the right-hand wheel of the rear axle, as shown in Figure 21. The tests on this vehicle followed those of the 5- and 6-axle 48 ft (14.63 m) semis [8,9], and the steady circular turn test had clearly caused the severe wear on the outer edge of this tire. The outrigger assembly was additional to normal trailer equipment, and the characteristics of the trailers were, therefore, somewhat atypical at least in the empty condition.

It is not possible to make any meaningful remarks on the effect these factors might have had on the results. The results presented pertain to the particular vehicle tested, and results different in some respects might be obtained for another vehicle at another time.

This vehicle was considered an easy vehicle to drive by the test driver. It tracked very well, but required considerably more effort to manoeuvre than either the 45 ft (13.72 m) semi [2] or the 5-axle 48 ft (14.63 m) semi [8], because of the two lowered airlift axles. It did, however, require a little less space to manoeuvre than these vehicles. It was clearly evident to the test driver, with the loaded vehicle on a wet surface, that the resistance to turning of the trailer, which caused the additional effort to manoeuvre, would require greater attention by the driver on the highway as there was less control available. The vehicle exhibited high stability in all dynamic manoeuvres. However, the trailer centre of gravity was quite low -- 1.77 m (70 in) from the ground. The centre of gravity of some loads can result in the trailer centre of gravity rising to 2.5 m (100 in) or more from the ground, which would reduce the rollover threshold to around 0.3 g [15]. The lane change would then likely have resulted in rollover at some speed much less than 95 km/h.

6/ CONCLUSIONS

A 7-axle tractor semitrailer combination was tested by the Ontario Ministry of Transportation and Communications, as part of the CCMTA/RTAC Vehicle Weights and Dimensions Study. The vehicle was designated as of particular interest by the study.

The vehicle was subjected to turning, air brake system, lateral/directional and roll stability, and trailer sway tests. A demonstration of straight-line braking was also conducted. Tests were conducted with an empty vehicle on a low-friction surface and a loaded vehicle on high-friction surface.

The length of this vehicle clearly contributed to the significant space required to make turns, though it required less space than a comparable 5-axle semi.

The air brake system was relatively fast and well balanced.

The lateral/directional stability of the vehicle was excellent, both empty on a low-friction surface and loaded on a high-friction surface. Stability varied little with speed up to 100 km/h. The roll stability was high, primarily because the trailer centre of gravity was low. A higher centre of gravity would significantly reduce the rollover threshold.

7/ REFERENCES

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[3] Billing, J.R., and Mercer, W., "Demonstration of Baseline Vehicle Performance: A-Train Double," Ontario Ministry of Transportation and Communications, Transportation Technology and Energy Branch, Report CV-86-03, June 1986.

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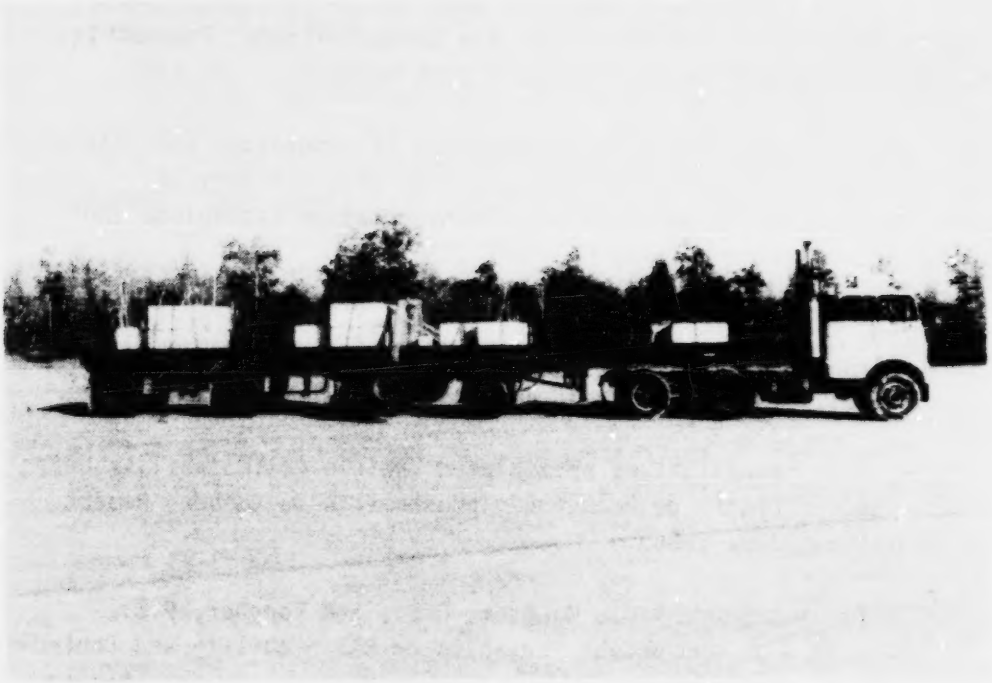


Figure 1/ 7-Axle 48 ft Semi, View of Vehicle

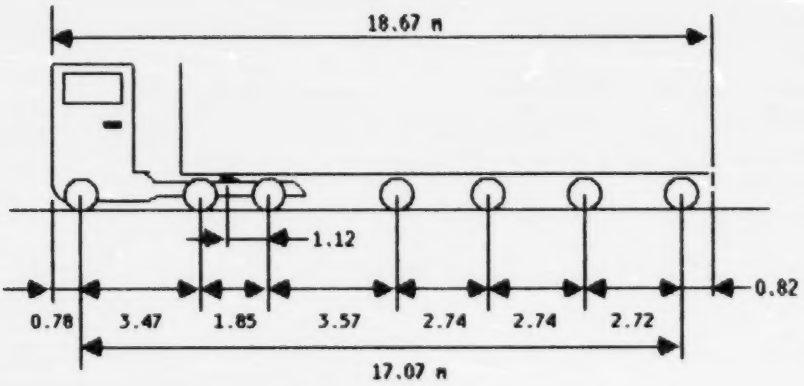


Figure 2/ 7-Axle 48 ft Semi, Vehicle Dimensions

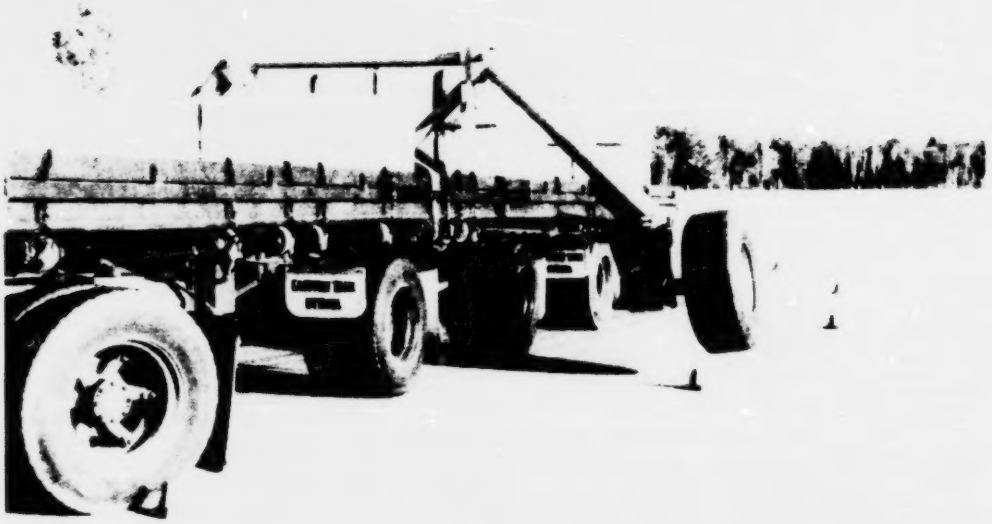


Figure 3/ 7-Axle 48 ft Semi,
Offtracking

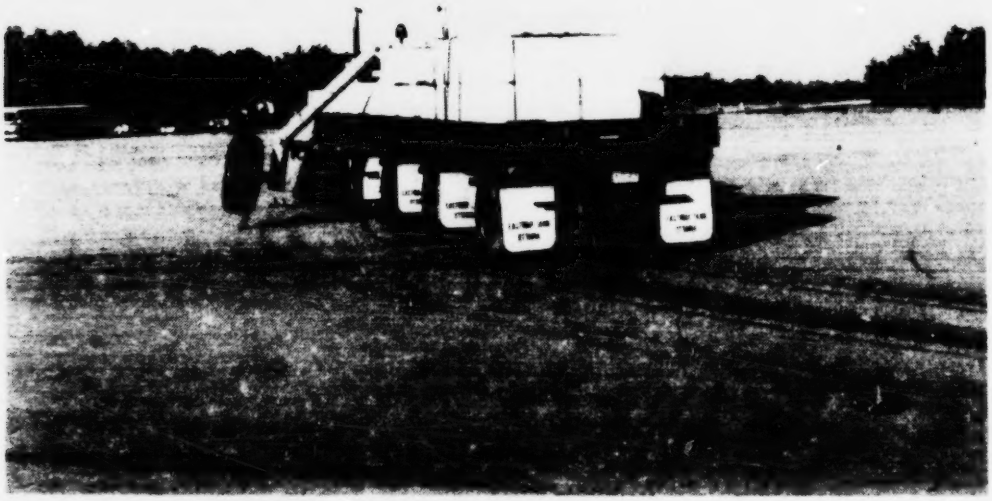
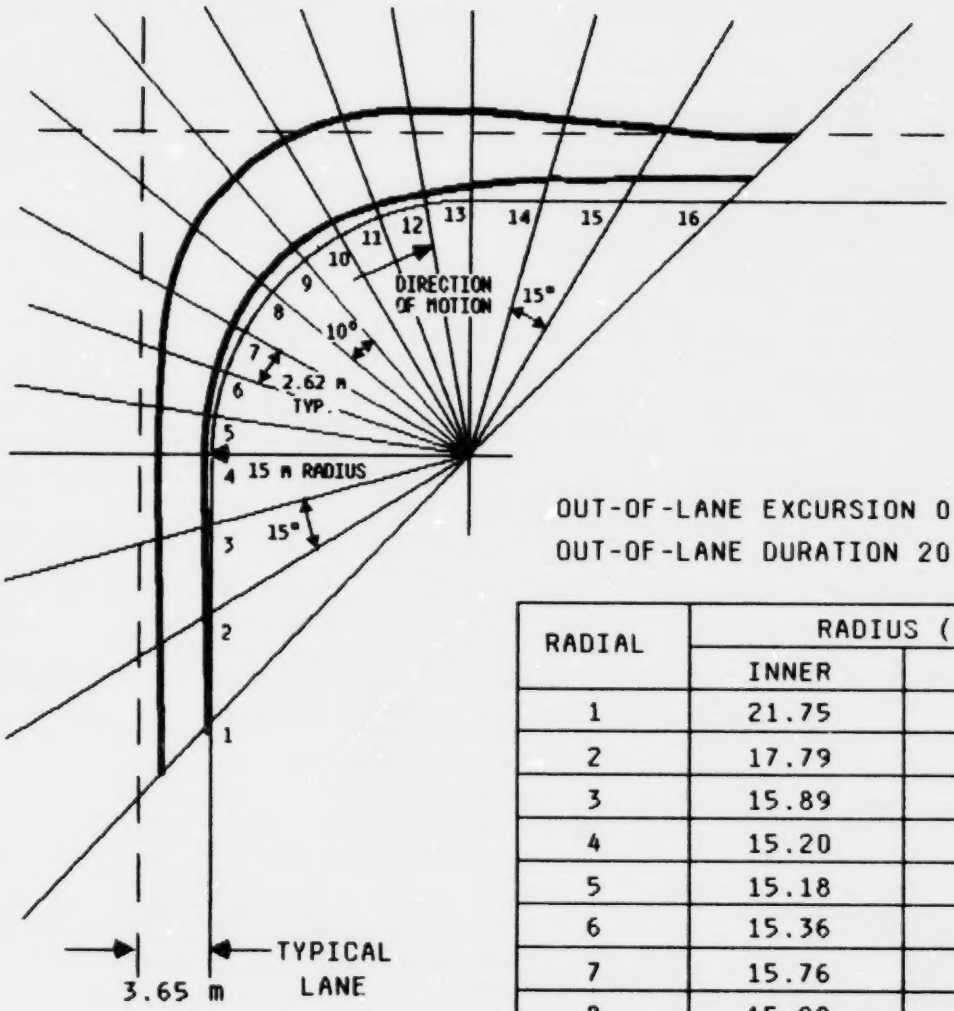


Figure 4/ 7-Axle 48 ft Semi,
Clockwise Final Offtracking



OUT-OF-LANE EXCURSION 0.8 m

OUT-OF-LANE DURATION 20.4 m

RADIAL	RADIUS (m)	
	INNER	OUTER
1	21.75	-
2	17.79	-
3	15.89	-
4	15.20	17.80
5	15.18	17.90
6	15.36	18.48
7	15.76	19.61
8	15.99	20.44
9	15.76	21.10
10	15.43	21.23
11	15.26	20.95
12	15.30	20.07
13	15.59	19.75
14	16.50	20.10
15	18.68	21.96
16	22.54	26.28

Figure 5/ 7-Axle 48 ft Semi, Right-Hand Turn Swept Path

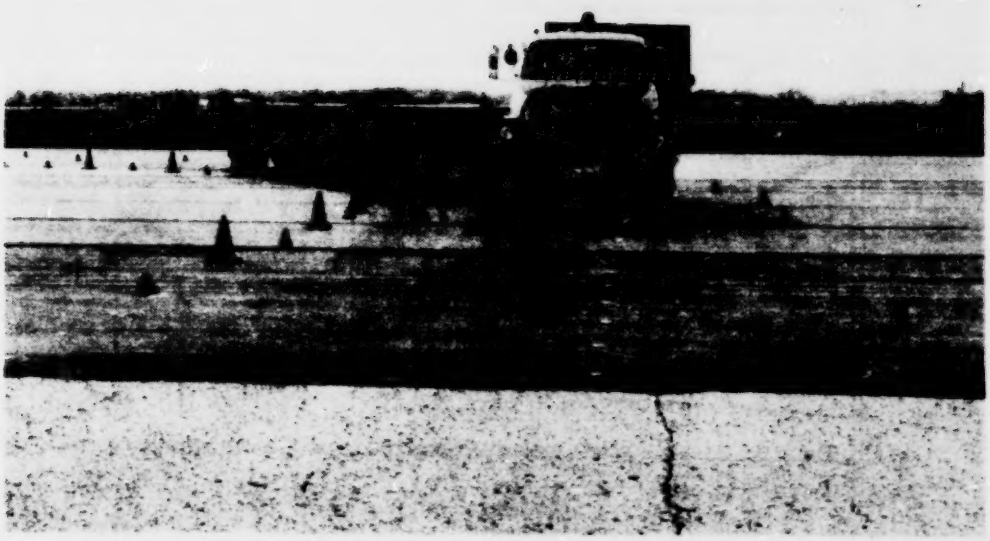


Figure 6/ 7-Axle 48 ft Semi, Right-Hand Turn

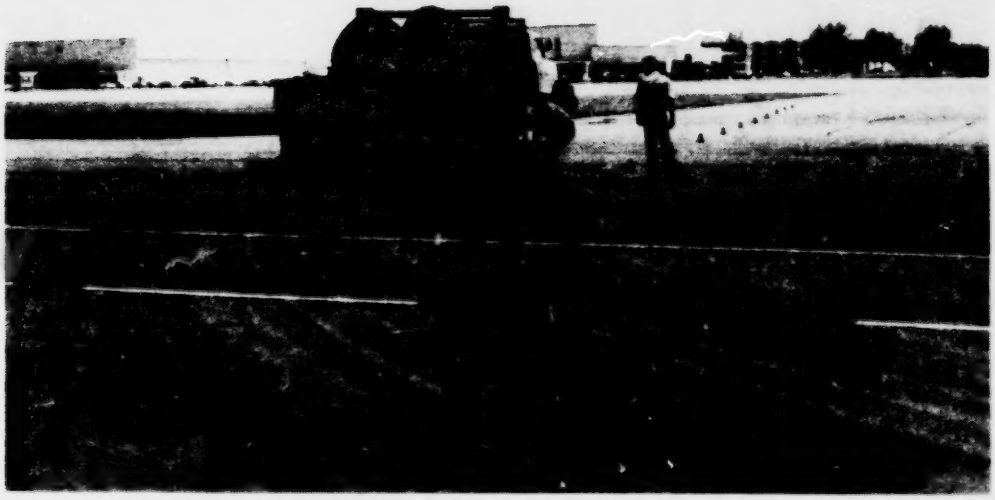
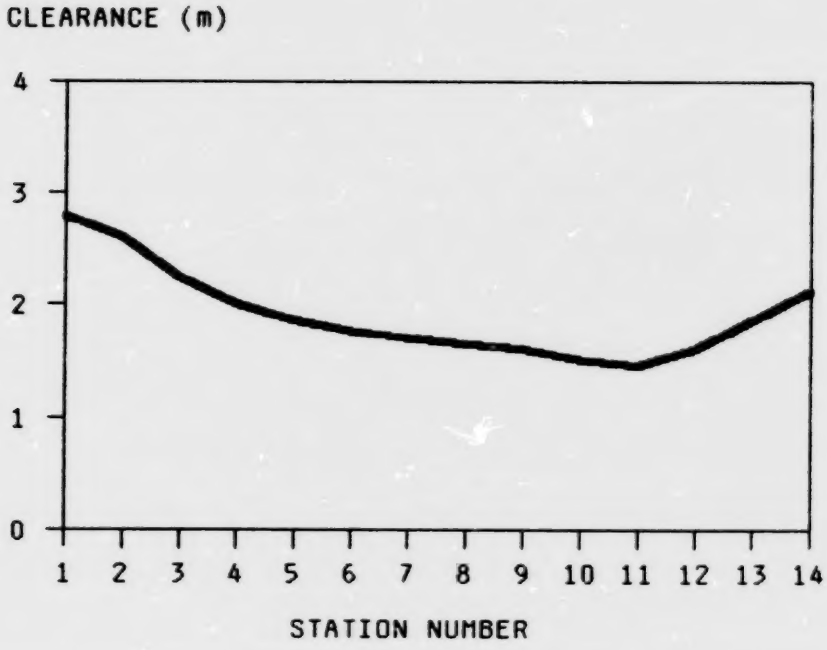


Figure 7/ 7-Axle 48 ft Semi, Channelized Right Turn



STATION NUMBER	CLEARANCE (m)
1	2.78
2	2.59
3	2.25
4	2.00
5	1.86
6	1.77
7	1.70
8	1.65
9	1.61
10	1.50
11	1.47 *(LOW)
12	1.60
13	1.86
14	2.13

Figure 8/ 7-Axle 48 ft Semi, Channelized Right-Turn Clearance from Inner Curb

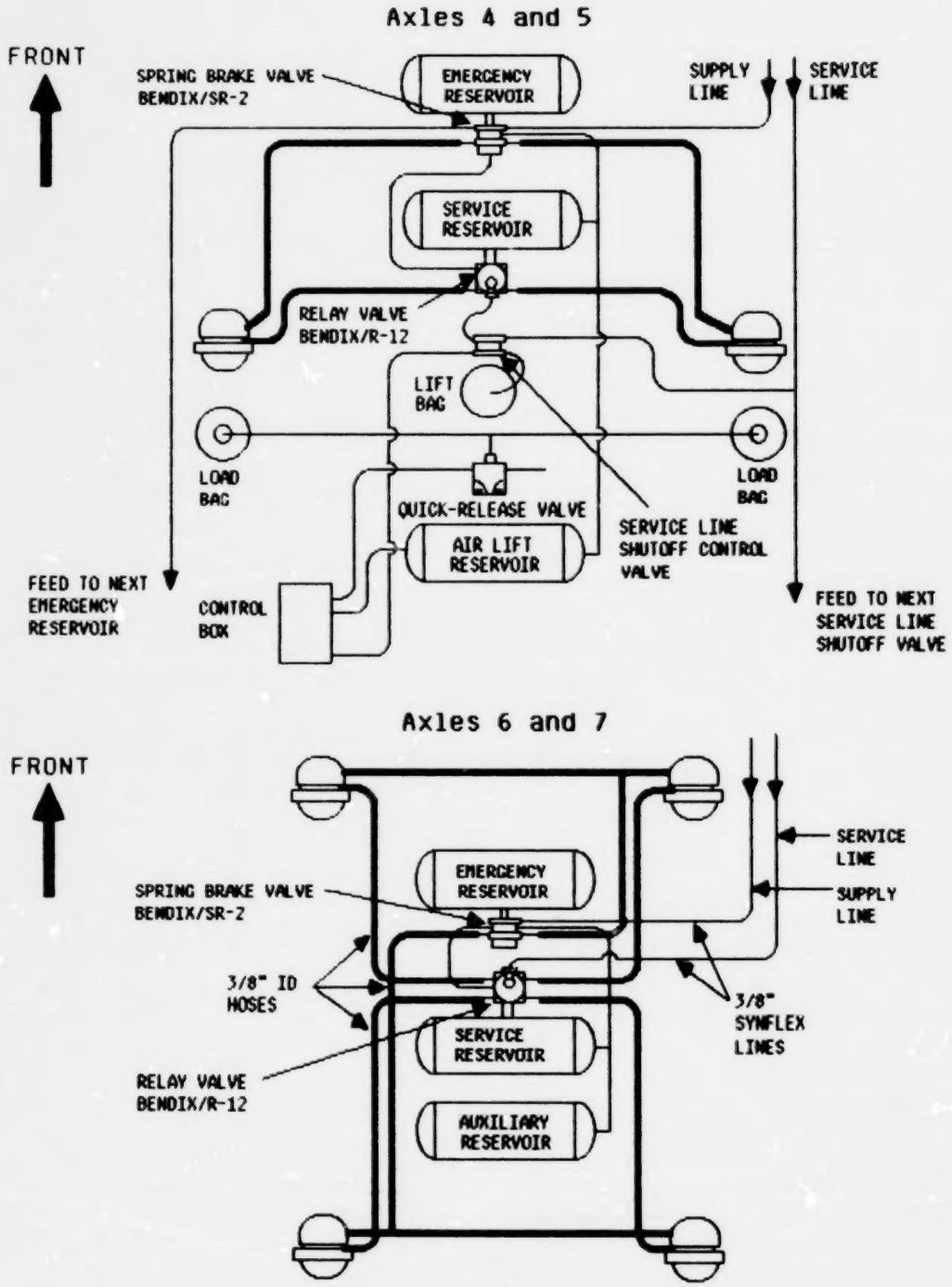


Figure 9/ 7-Axle 48 ft Semi,
Air Brake System Schematic

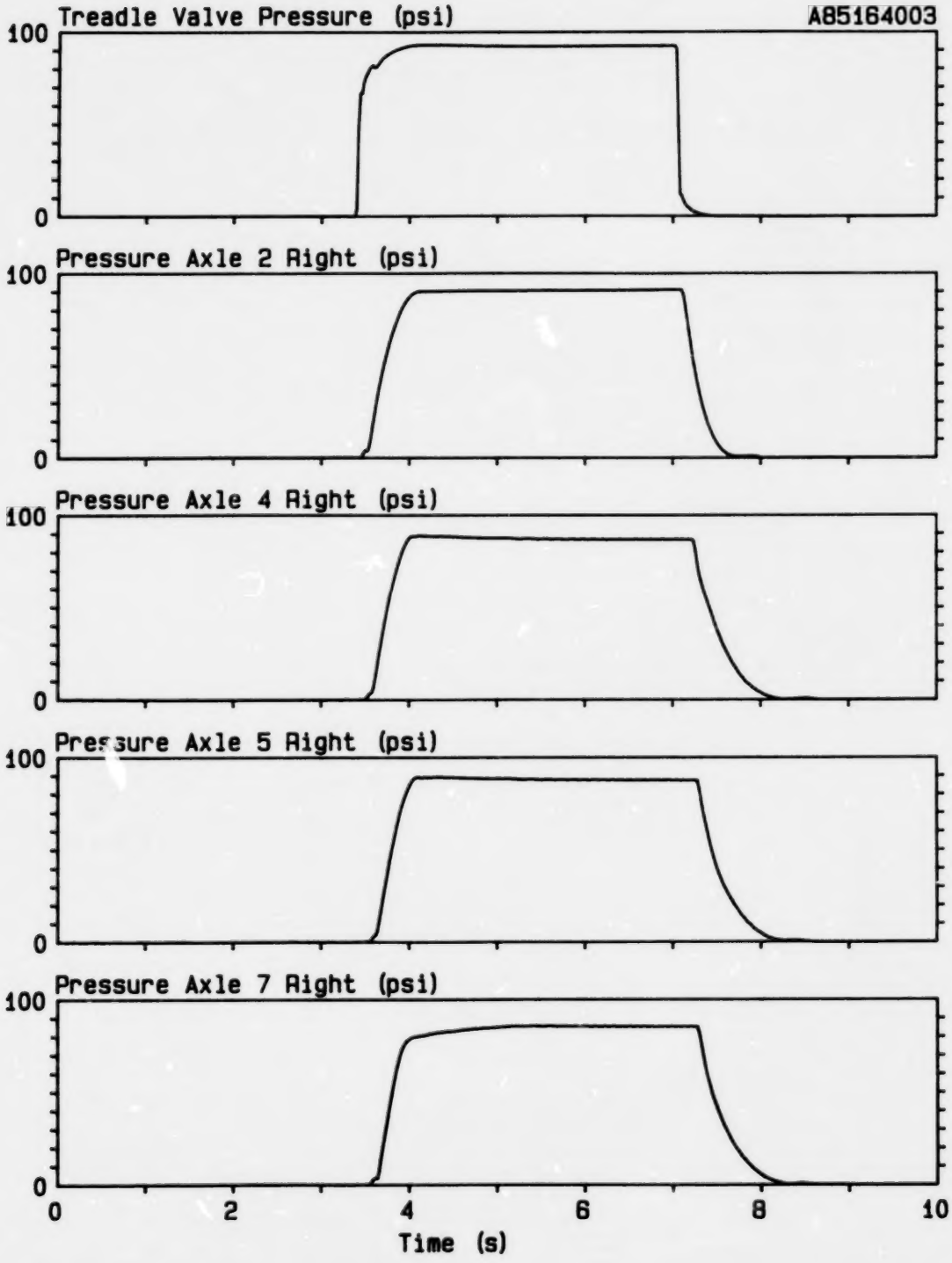


Figure 10/ 7-Axle 48 ft Semi,

Air Brake Application and Release

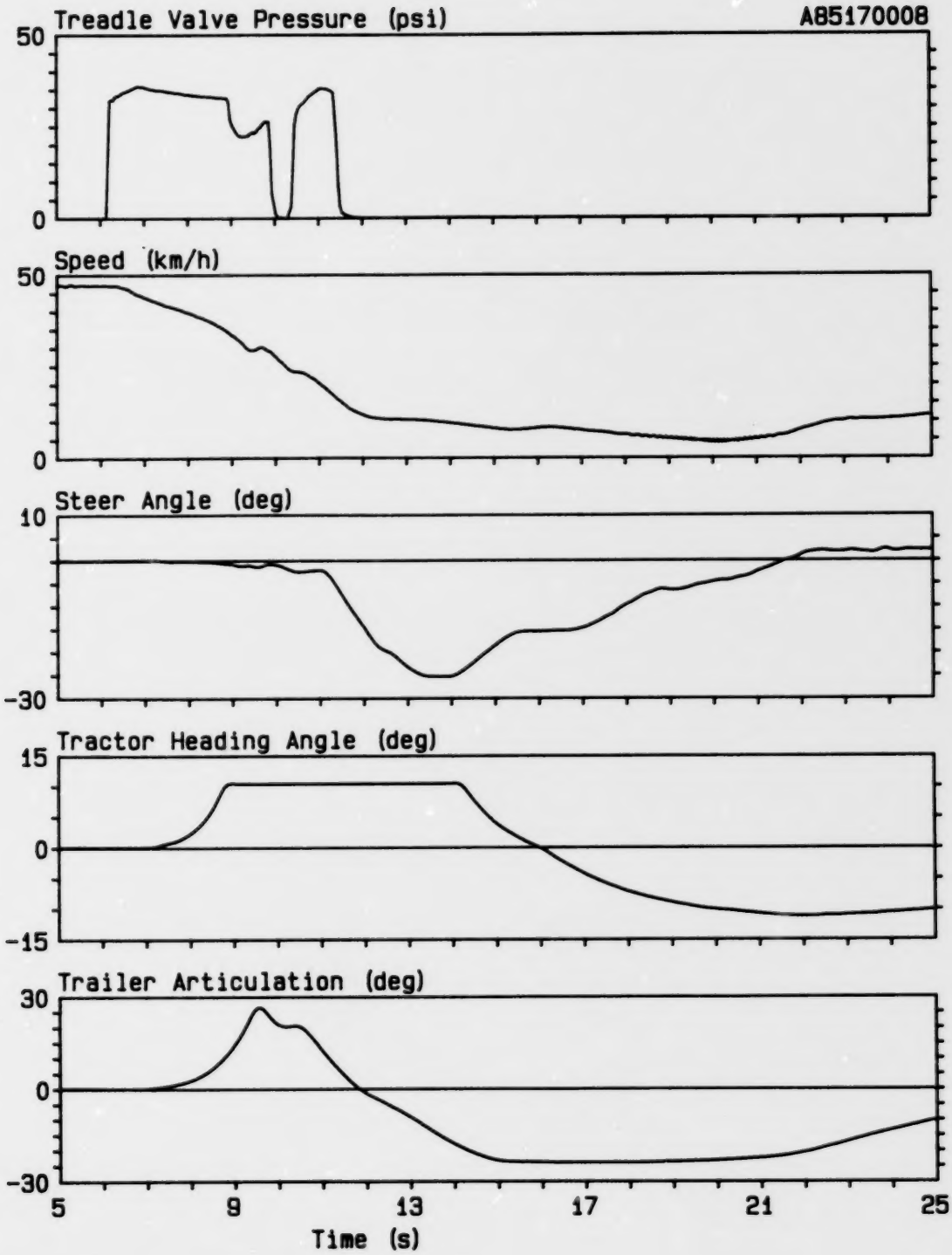


Figure 11/ 7-Axle 48 ft Semi,

Vehicle Response to Straight-Line Braking

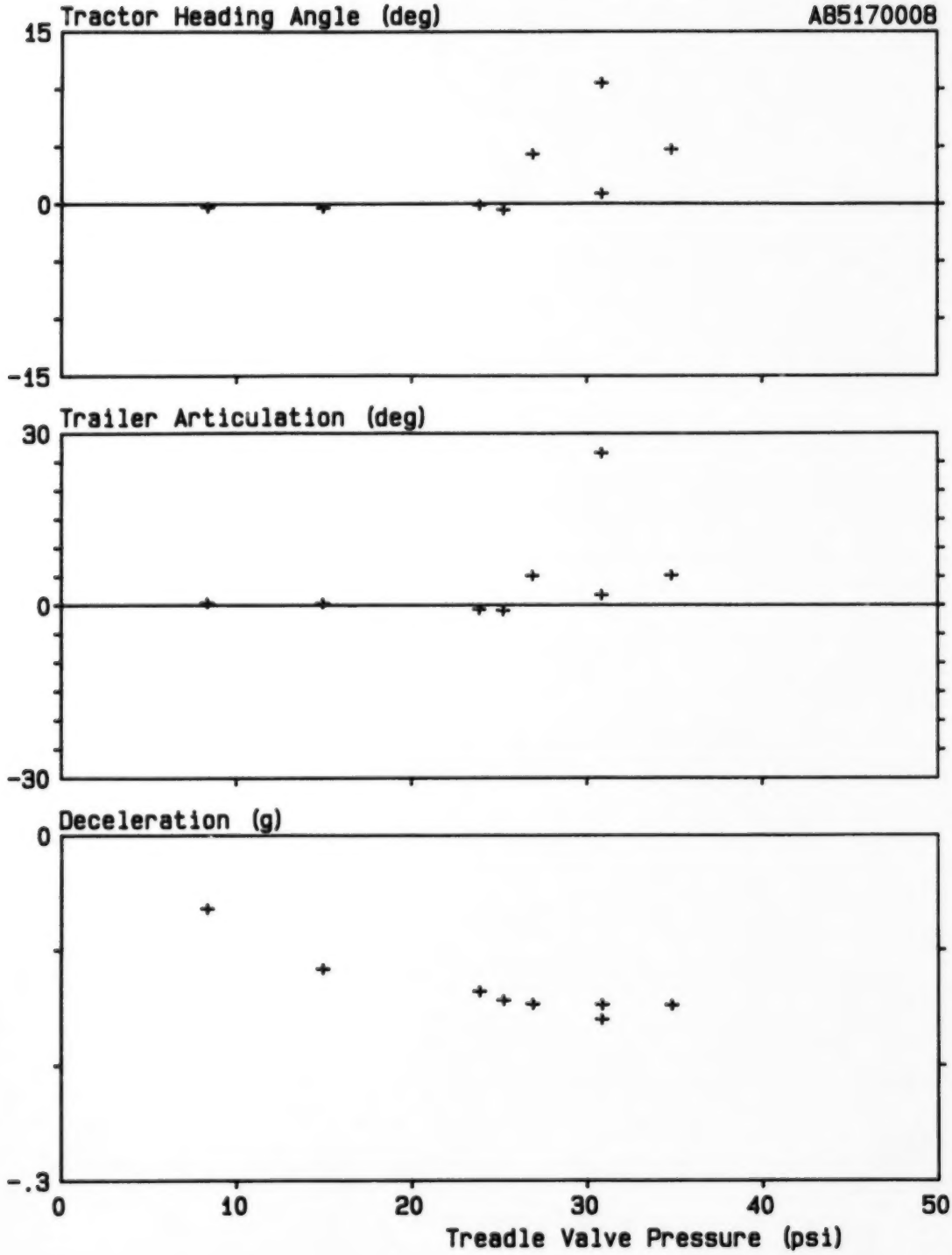


Figure 12/ 7-Axle 48 ft Semi, Straight-Line Braking Responses vs Treadle Valve Pressure

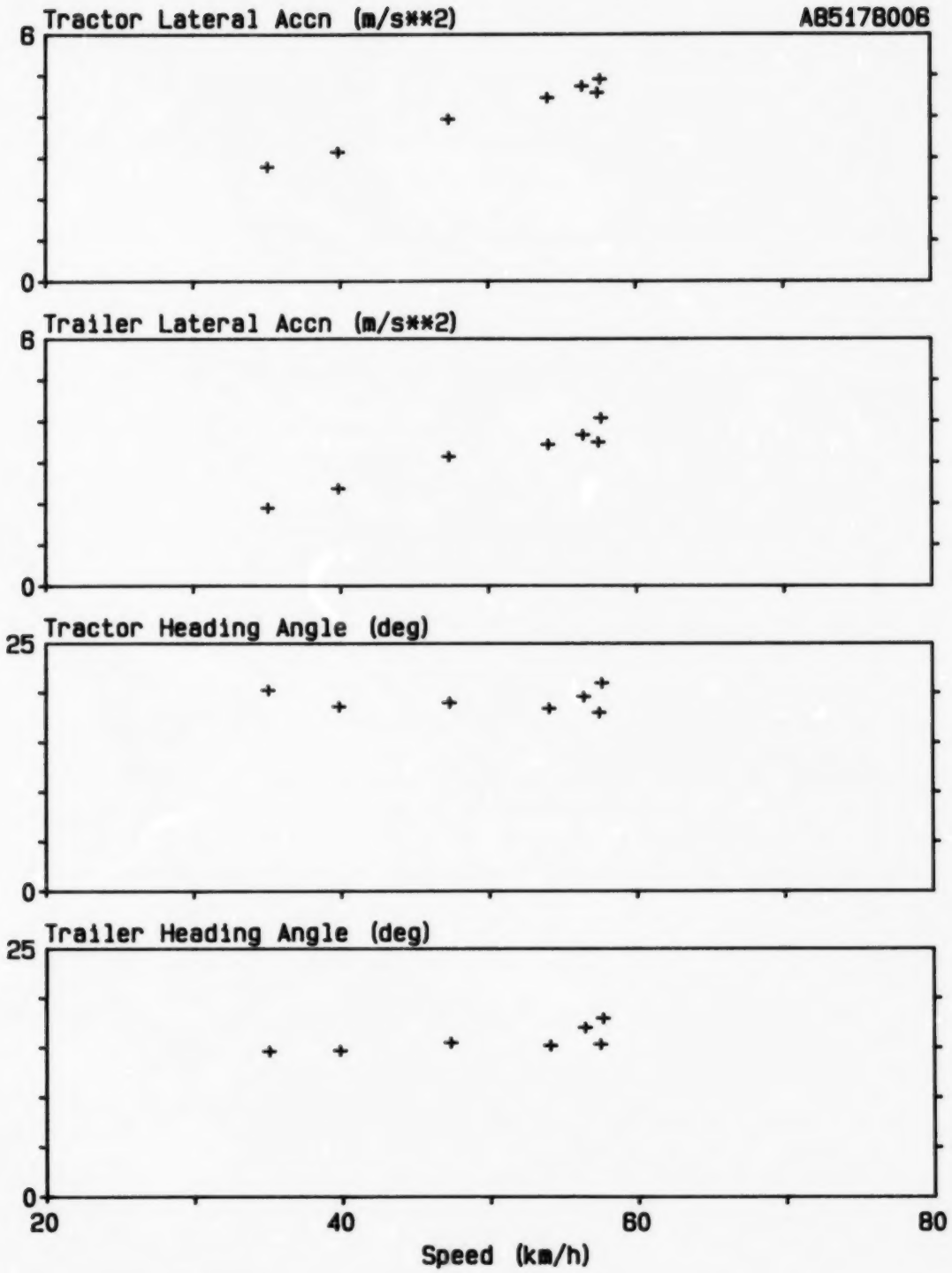


Figure 13/ 7-Axle 48 ft Semi, Evasive Manoeuvre, Peak-to-Peak Responses vs Speed

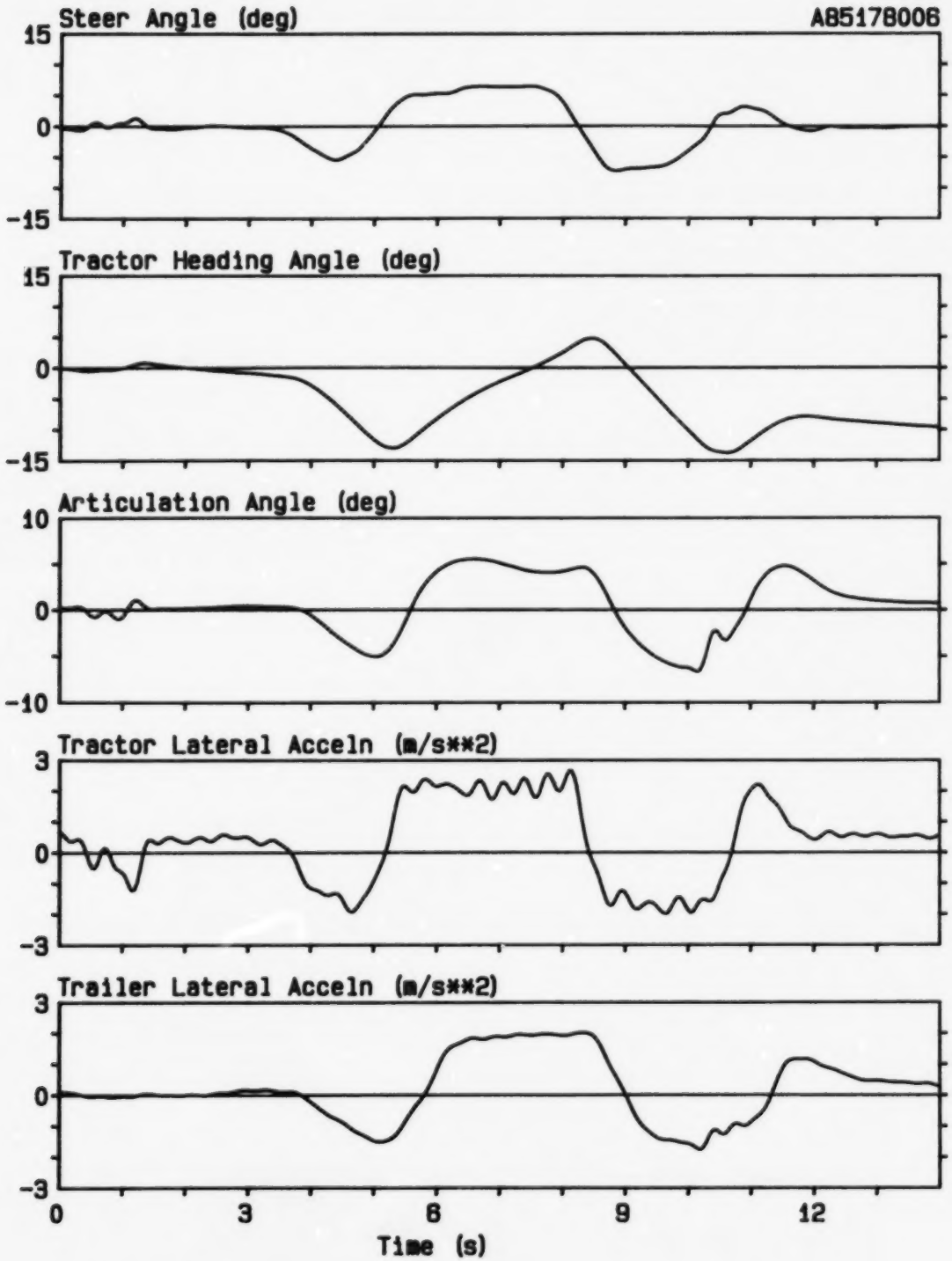


Figure 14/ 7-Axle 48 ft Semi,

Vehicle Response in Evasive Manoeuvre

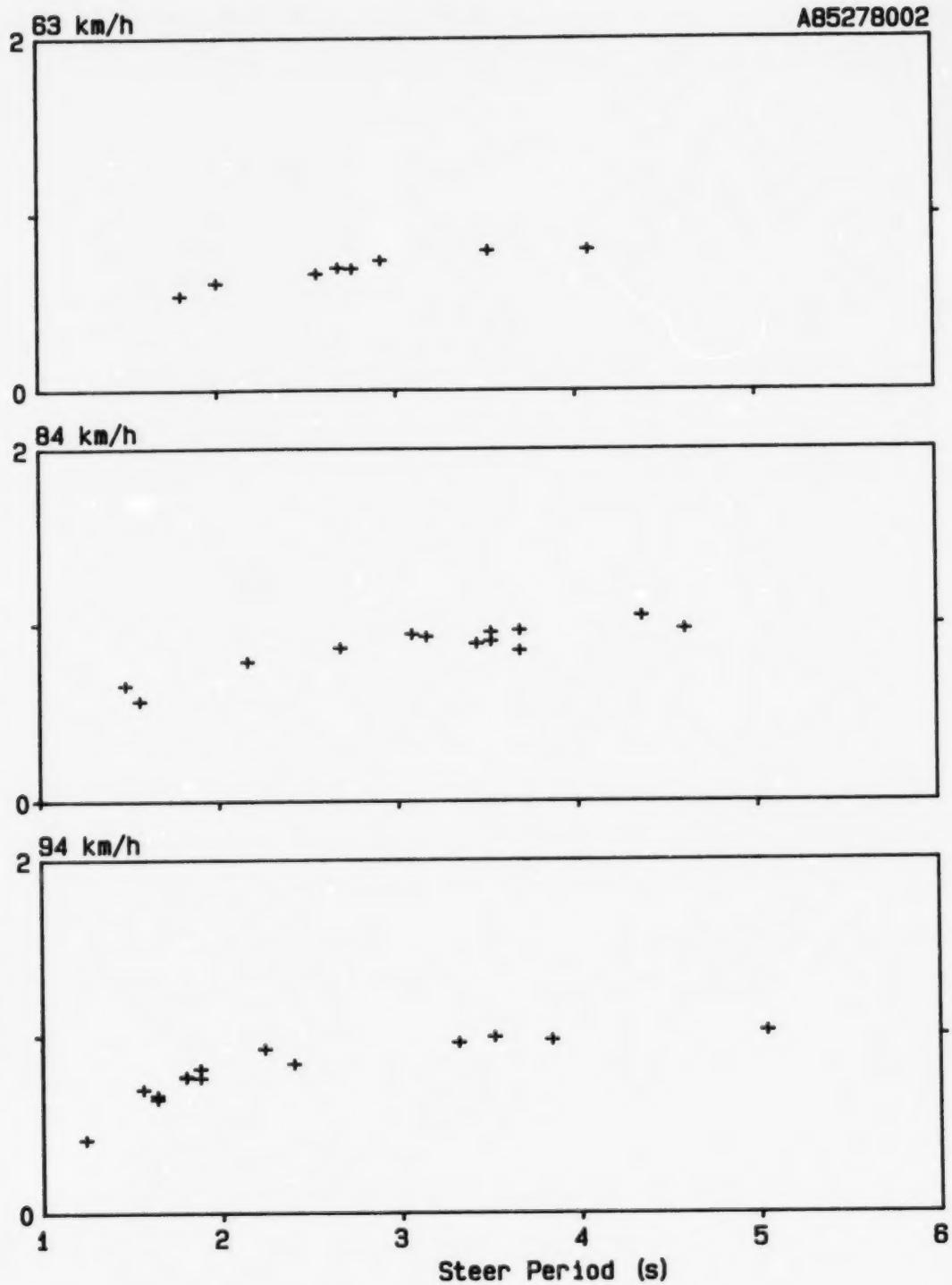


Figure 15/ 7-Axle 48 ft Semi,

Rearward Amplification of Lateral Acceleration

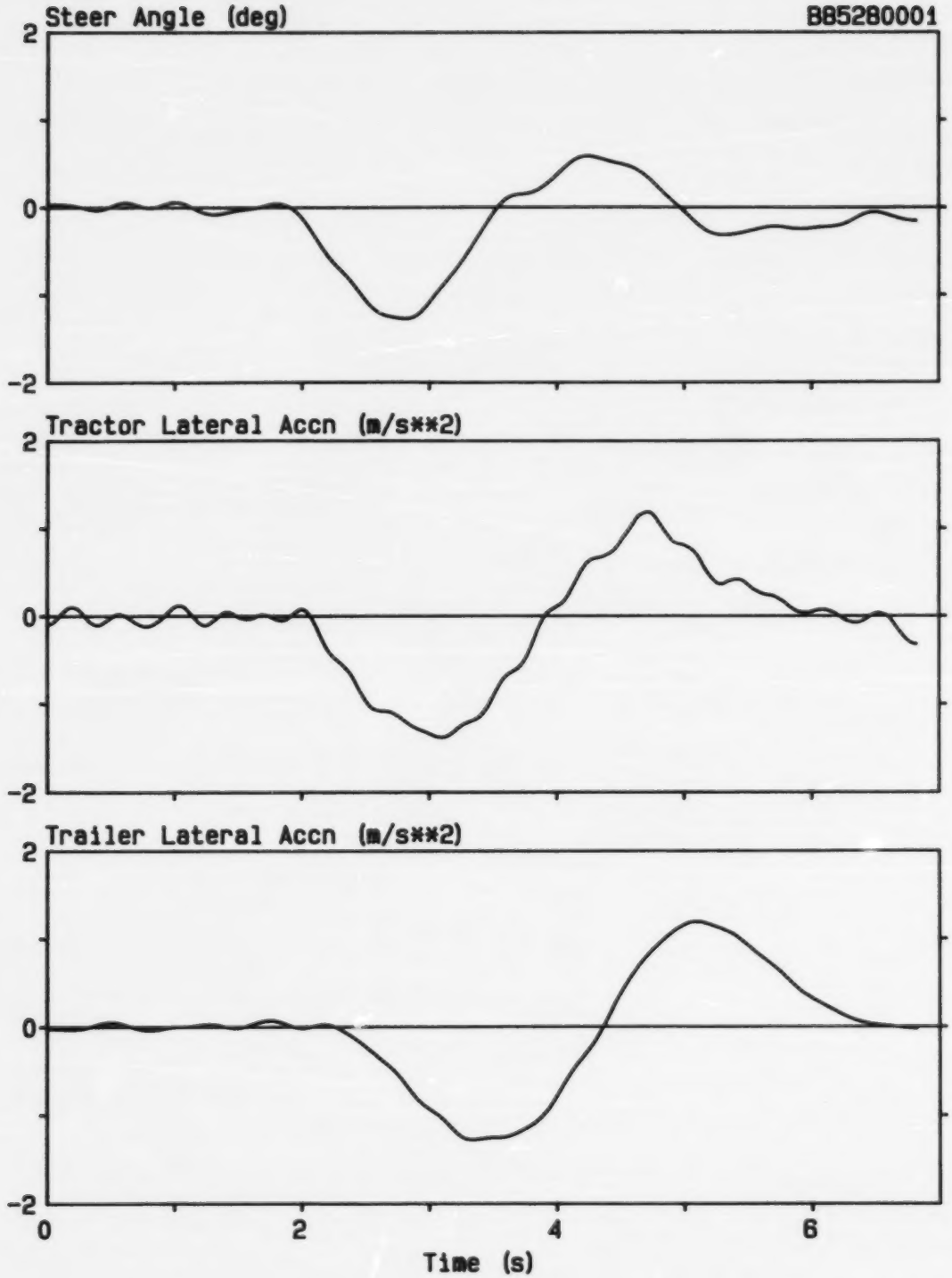


Figure 16/ 7-Axle 48 ft Semi,

Vehicle Response to Sinusoidal Steer at 94 km/h

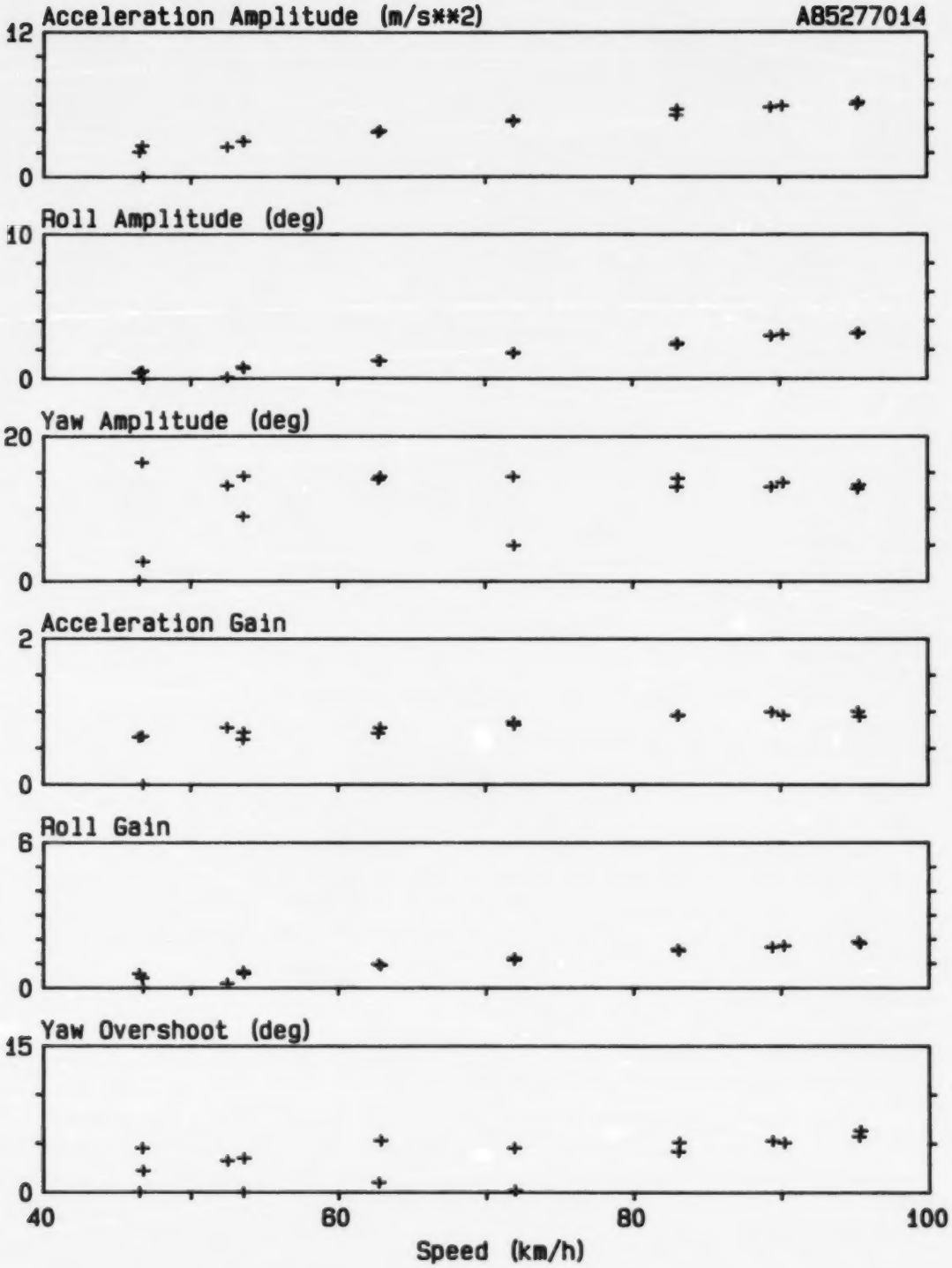


Figure 17/ 7-Axle 48 ft Semi, Lane Change,
Vehicle Responses vs Speed

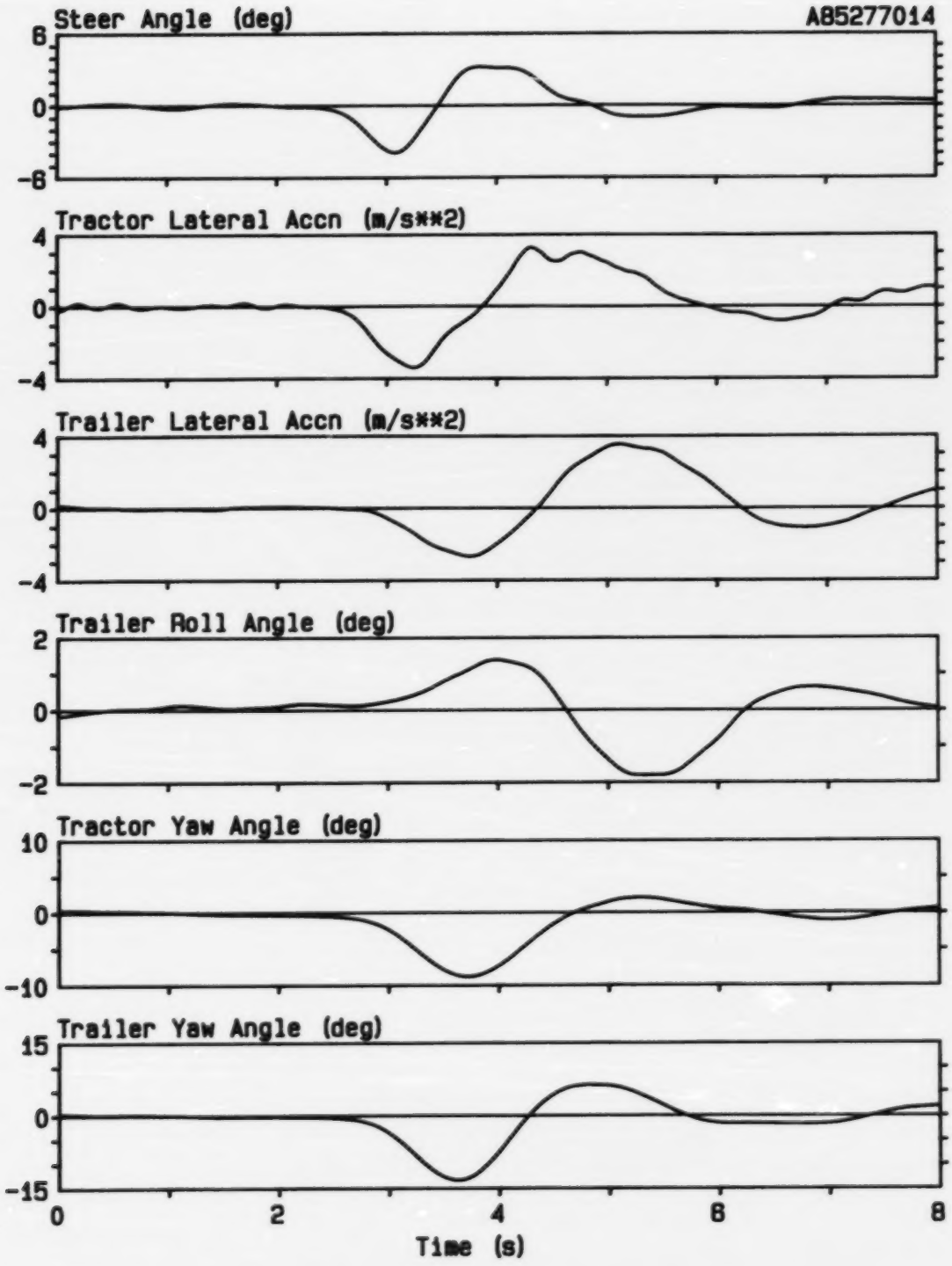


Figure 18/ 7-Axle 48 ft Semi, Lane Change,
Vehicle Responses at 84 km/h

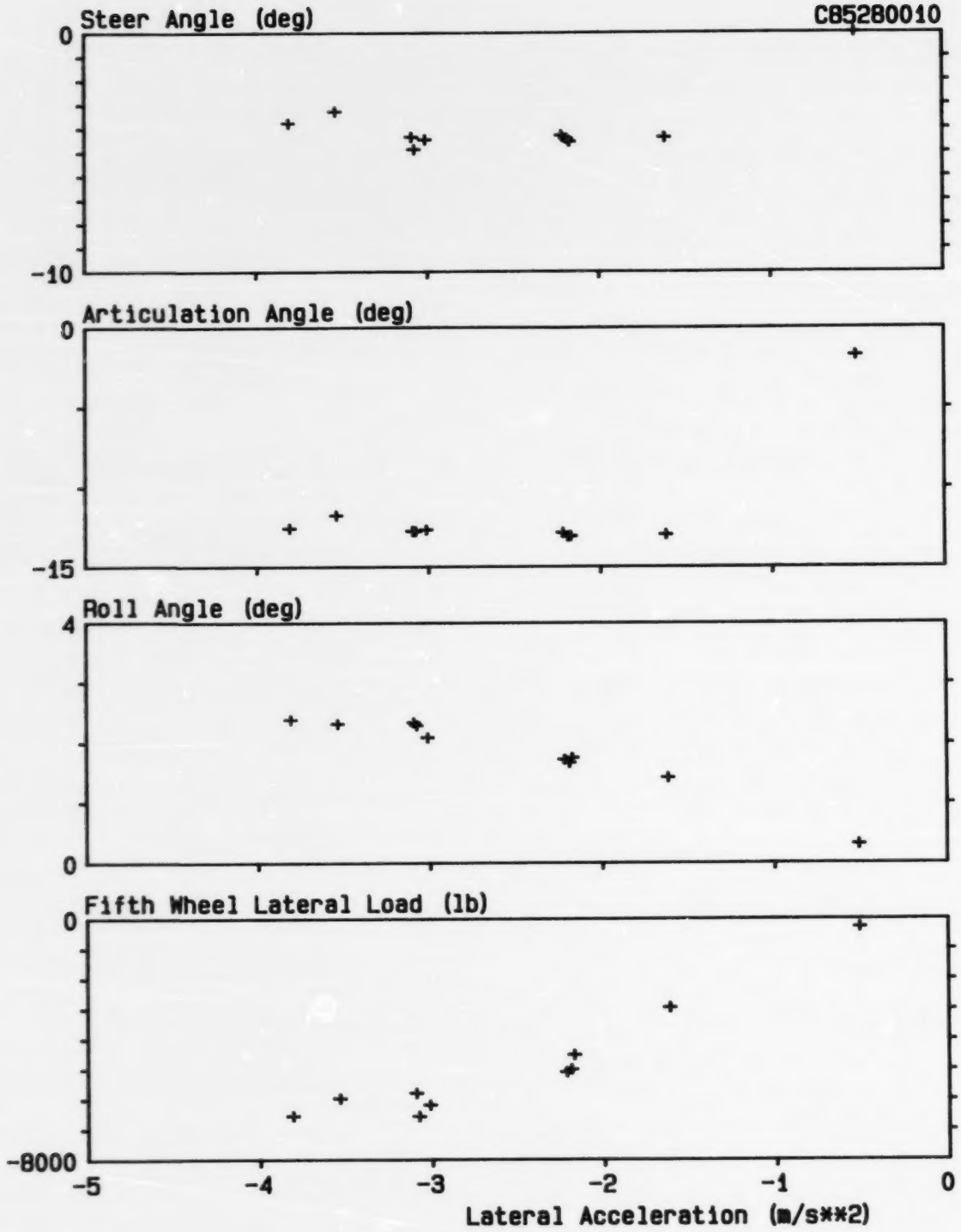


Figure 19/ 7-Axle 48 ft Semi, Steady Circular Turn, Vehicle Responses vs Tractor Lateral Acceleration

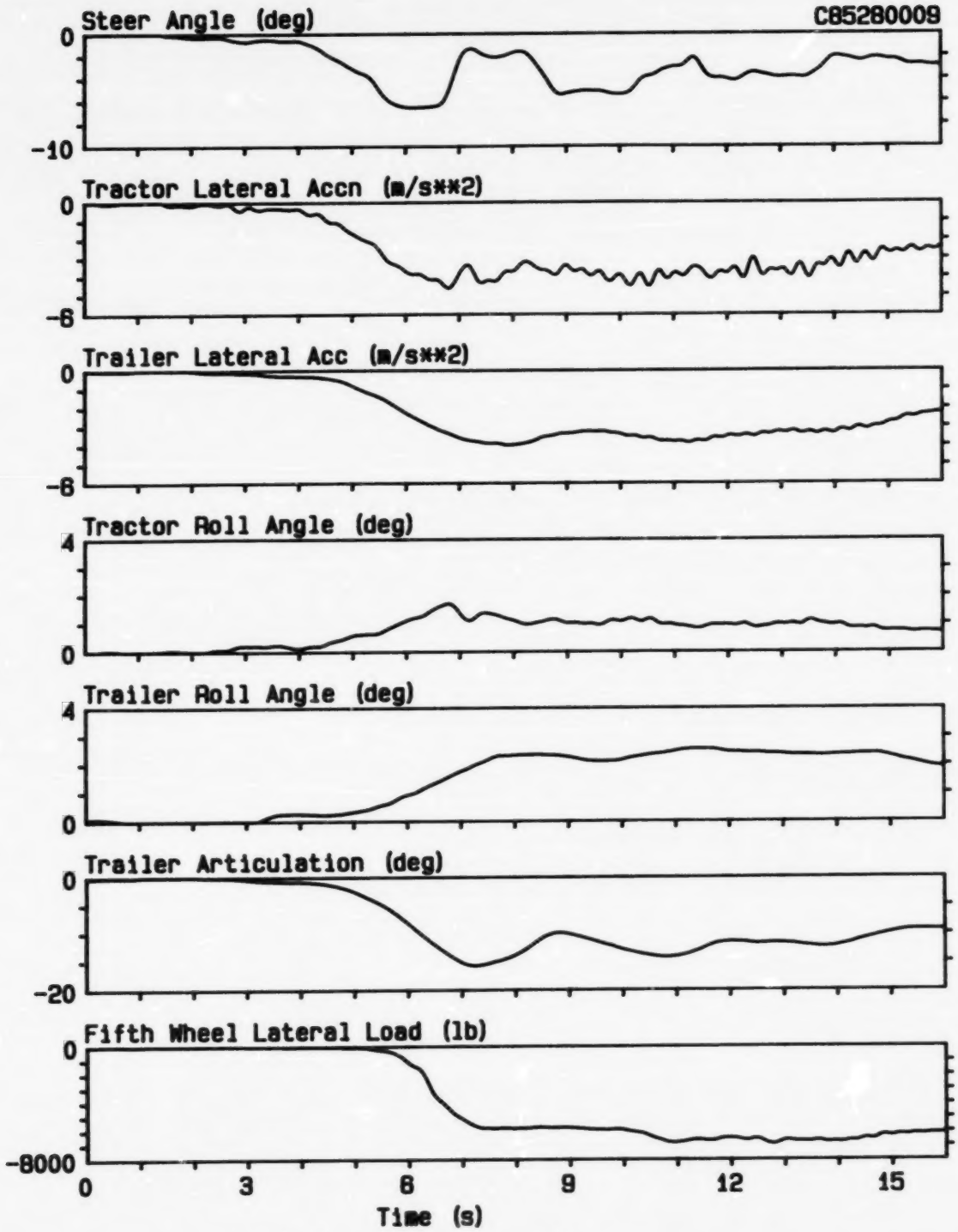


Figure 20/ 7-Axle 48 ft Semi, Steady Circular Turn, Vehicle Responses at 53 km/h

Figure 21/ 7-Axle 48 ft Semi, Wear Pattern on Right Rear Outer Tire After Steady Circular Turn Test

Figure 22/ 7-Axle 48 ft Semi on Tilt Table